Yamato 793169
Unbrecciated basalt
6.09 g

Figure 1: Mare diabase Yamato 793169; dimensions in the field were 1.8 x 1.7 x 1.1 cm (Yanai and Kojima, 1991).

Introduction

Yamato 793169 (Fig. 1) was found on bare ice near the Minami-Yamato Nunataks, by the JARE-20 meteorite search party December 8, 1979 (Fig. 2 and 3). This 1.8 x 1.7 x 1.1 cm nearly complete stone was covered by black fusion crust with white laths of plagioclase on the surface (Fig. 1).   Although it was originally classified as an unbrecciated eucrite, it was quickly reclassified as a lunar diabase (Yanai and Kojima, 1991).

Petrography and Mineralogy

Y-793169 exhibits an unbrecciated sub-ophitic texture of medium to coarse-grained pyroxene (56%) and plagioclase (42%), with minor ilmenite (1%), spinel (1%), glass, and rare olivine (Fig. 4). Pyroxene is the coarsest phase, with 1 to 3 mm somewhat fractured crystals, and is zoned from low Ca and Mg#=50 cores to Ca- and Fe-rich rims (Fig. 5). Plagioclase is rhombic or lath shaped from 1 to 1.5 mm, partially maskelynitized, and ranges from An_{85} to An_{96} (Fig. 6). The pyroxene compositional trends are more similar to VLT basalts than to low Ti Apollo 12 or 15 basalts (Takeda et al., 1993). Mikouchi (1999) studied the glass and feldspars and proposed that the diaplectic glass was formed from feldspar by impact, but that there was also later thermal recrystallization of feldspar. The latter event may be recorded by K-Ar system (Torigoye-Kita et al., 1995; see below). Spinels have two compositional groupings – a TiO_2-rich ulvospinel and a more Cr-rich spinel (Fig. 7) similar to that found in early stages of crystallization in Apollo 12 and 15 basalts (Arai et al., 1996).
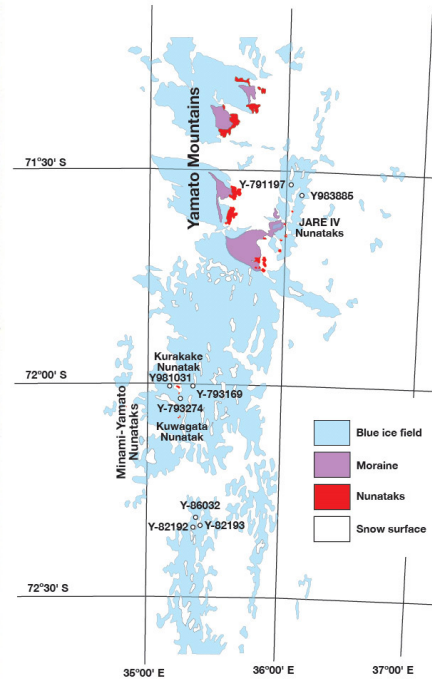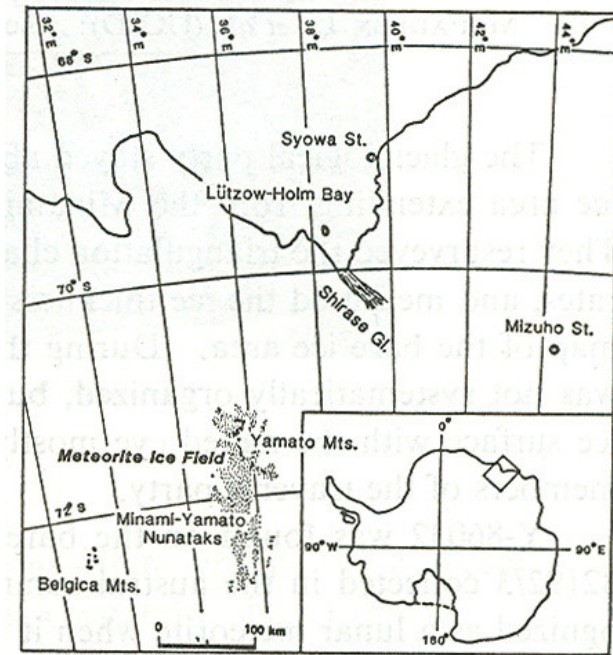
Figure 2: Location map for the Yamato Mountains. Figure 3: Detailed location map for the Yamato lunar meteorites (map courtesy of the NIPR). Y793169 is near the middle of the map.
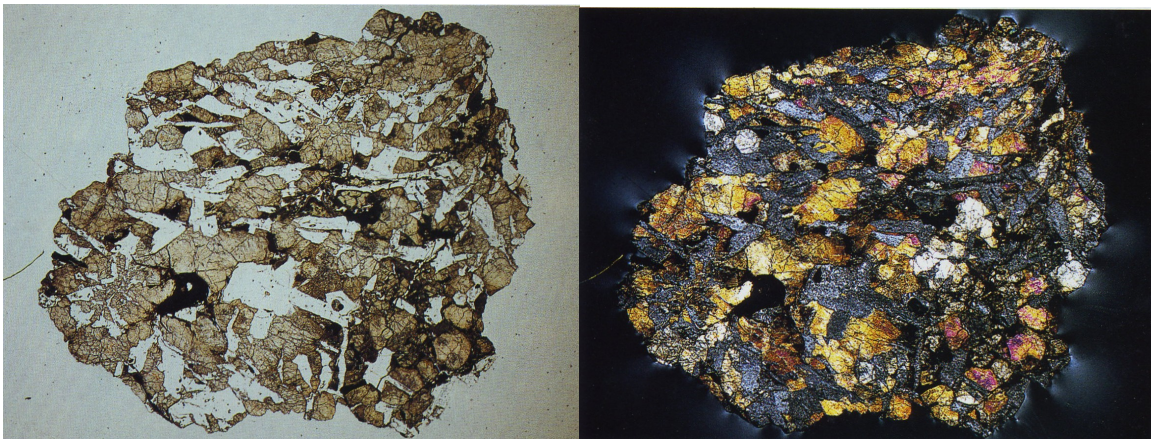

Figure 4: plane polarized light (left) and crossed polars (right) photomicrographs of Yamato 793169. Field of view is 2 mm (from Yanai and Kojima, 1991).
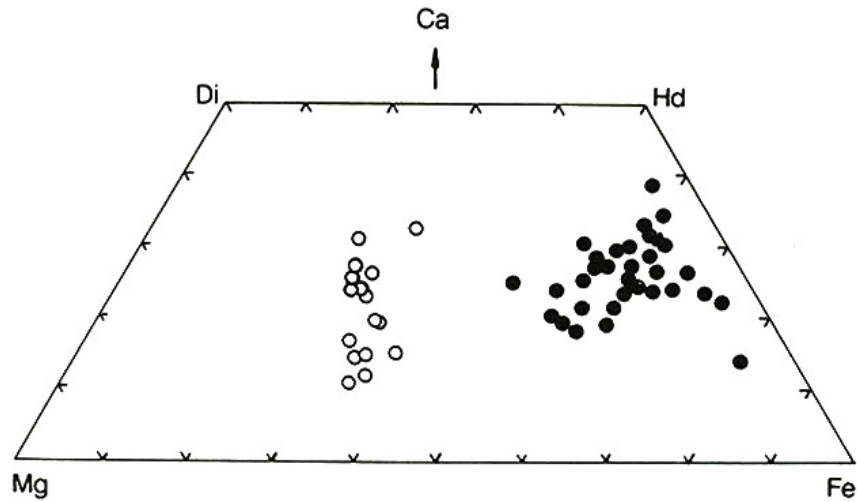
(b) Y-793169,51

Figure 5: Pyroxene cores (open) and rims (closed) from Y-793169 (Takeda et al., 1993).
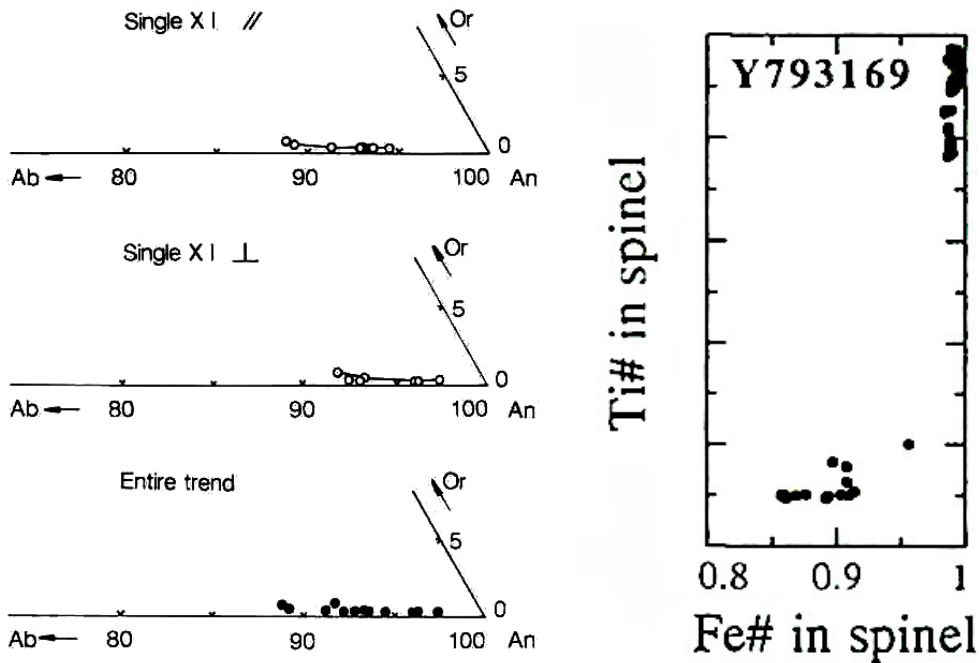
Y-793169,51 Plagioclase

Figure 6 (left): Plagioclase compositions from Y-793169 (Takeda et al., 1993).
Figure 7 (right): Spinel compositional groupings into Ti-rich ulvospinels (late) and Cr- and Al-rich (early; from Arai et a.l, 1996).

Chemistry

The bulk composition of Y-793169 is generally similar to other low Ti and VLT mare basalts from the Luna and Apollo collections, but there are some significant differences (Table 1). First, it is a low MgO sample, suggesting it is more evolved than many of the

Apollo suites (Fig. 8). Second, it contains much higher Sc than many mare basalts (Fig. 9). Although in general it is slightly enriched in heavy relative to light REE, it is relatively flat with only a very small Eu anomaly (Fig. 10).

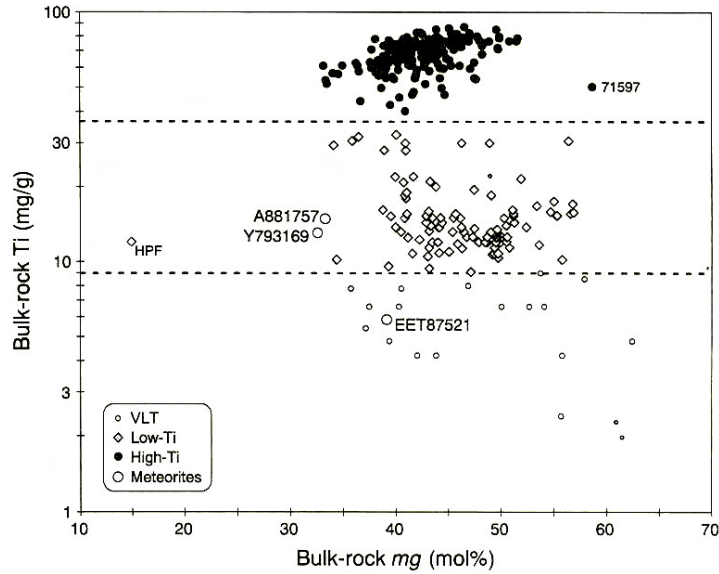
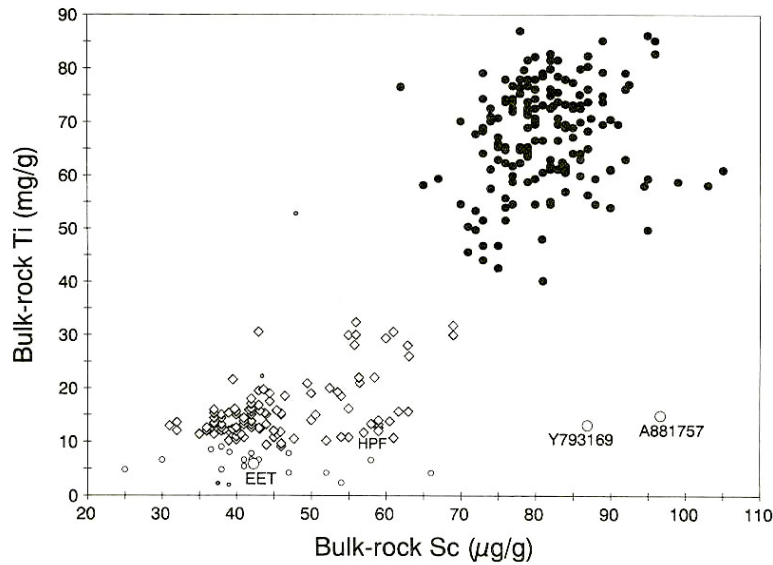*Figure 8: Mg vs Ti for Y-793169 compared to many Apollo low Ti and high Ti basalts (from Warren and Kallemeyn, 1993).*

Figure 9: Ti vs. Sc for Y-793169 compared to many Apollo low Ti and high Ti basalts (from Warren and Kallemeyn, 1993).
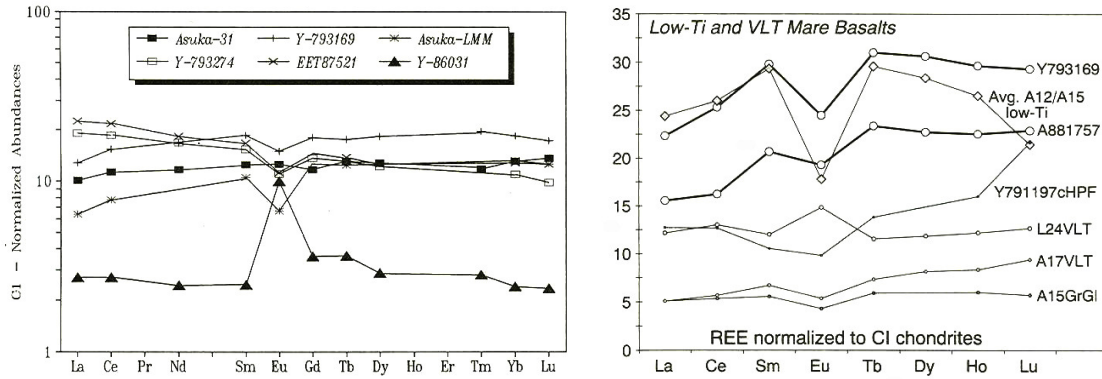
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Figure 10: Chondrite normalized REE for Y-793169 from two different studies (Koeberl et al., 1993; Warren and Kallemeyn, 1993).

Radiogenic age dating

K-Ar data for Y-793169 show evidence for a disturbance or thermal event, as the age derived is 1640 Ma (±90 Ma; Thalmann et al., 1996), much younger than the ages from other techniques. The Ar-Ar system shows evidence for disturbance, and yields ages as young as ~750 Ma (Torigoye-Kita et al., 1993) depending on the material, K-content, and T fraction. This is also true of more recent Ar-Ar age determinations by Fernandes et al. (2009). The latter obtain ages between 200-410 Ma and 3.8 to 3.9 Ga. The latter older ages are interpreted to be the crystallization ages, which are in agreement with other more robust chronometers as discussed next. For instance, U-Th-Pb dating yields ages near 3.8 to 3.9 Ga (Fig. 11; Torigoye-Kita et al. (1993, 1995). Similarly, the Sm-Nd system yields an age near 3.43 Ga (Fig. 12). Both Torigoye-Kita et al. (1993) and Mikouchi (1999) argue that a younger thermal event may be associated with the younger age. The low U/Pb and high Sm/Nd of Y-793169 are similar to those of Luna 24 and the terrestrial mantle, but different from Apollo 11, 12, 15 and 17 basalts (Fig. 13). Torigoye-Kita et al. (1995) suggest that this may be attributed to derivation from lunar mantle that did not experience volatile loss.

The combination of similar ages, mineralogy, bulk composition, and derived source region characteristics have led Arai et al. (2009) to conclude the Yamato 793169 is launch paired with Asuka 881757, Miller Range 05035, and Meteorite Hills 01210.
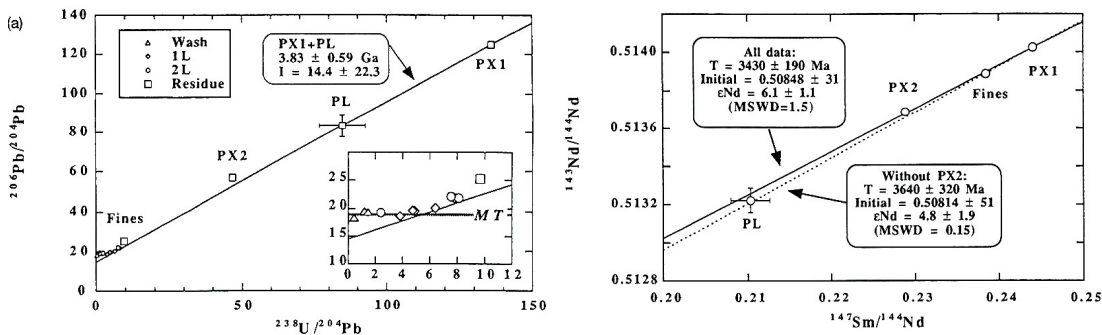

Figure 11 (left): Pb isochron based on ^{206}Pb and ^{238}Pb and pyroxene and plagioclase fractions from Y-793169 (from Torigoye-Kita et al., 1993).

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Figure 12 (right): Isochron for the Sm-Nd system yielding an age of 3.430 (±0.190) Ga, from Torigoye-Kita et al. (1993).
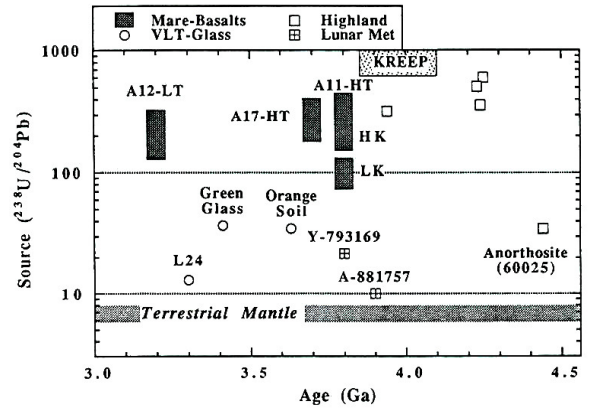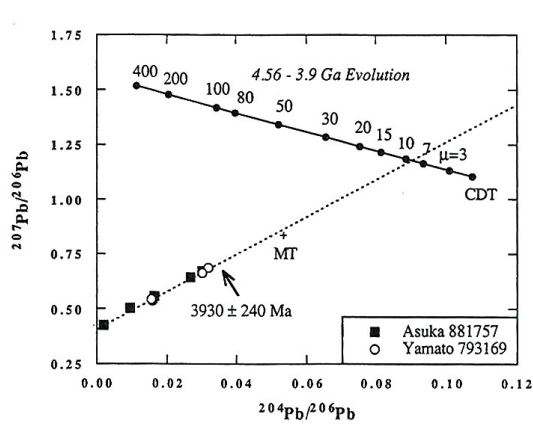

Figure 13: Low U/Pb values of Y-793169 ($\mu \sim 10$) compared to those calculated for other lunar samples and the terrestrial mantle (Torigoye-Kita et al.1993, 1995).

Cosmogenic isotopes and exposure ages

Yamato 793169 contains very little or no solar noble gases, indicating that it resided in the top layer of the lunar regolith for only a brief time, if at all (50 ±10 Ma based on ^{21}Ne, ^{38}Ar, ^{78}Kr, ^{83}Kr, and ^{126}Xe; Thalmann et al., 1996). The transit age (1.1 ±0.2 Ma; Fig. 14) and terrestrial ages (< 0.05 Ma) were determined by Nishiizumi et al. (1992) using ^{10}Be, ^{26}Al, and ^{36}Cl.

Figure 14: Ejection age of Y-793169 determined by Thalmann et al. (1996) at approximately 1 Ma.

Table 1a. Chemical composition of Yamato 793169
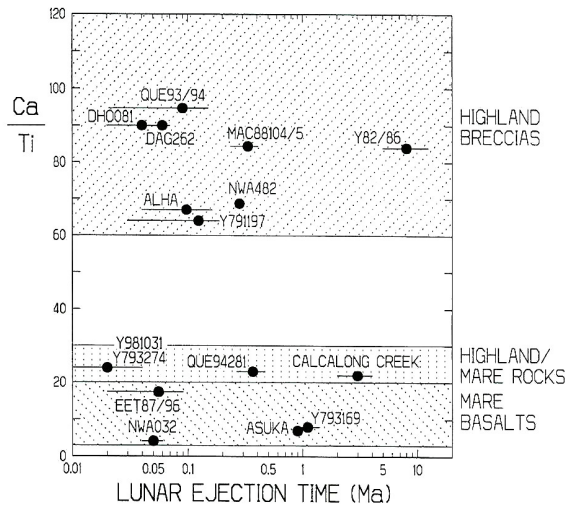
reference	1	2	2	3
weight		8.39	10.42	20
method	h	f,g	f,g	e,f,g
SiO_2 %	43.59			45.99
TiO_2	1.52			2.19
Al_2O_3	12.89			11.11
FeO	21.42	23.54	24.57	21.23
MnO	0.18			0.318
MgO	5.75			5.75
CaO	13.25			12.03
Na_2O	0.4	0.296	0.315	0.27
K_2O	0.13	0.065	0.064	0.062
P_2O_5	0.29			
S %	0.48			
sum				
Sc ppm		92.6	94.5	87
V				53
Cr	752	1770	1742	1620
Co		30.5	29.3	21.4
Ni		50	55	7.3
Cu				
Zn		5	4	1.35
Ga		3.8	3.1	3
Ge				2.2
As		0.21	0.18	
Se		0.39	0.31	
Rb		<4	2.1	
Sr		70	85	220
Y				
Zr		65	55	190
Nb				
Mo				
Ru				
Rh				
Pd ppb				
Ag ppb		<50	<20	
Cd ppb				<180
In ppb				
Sn ppb				
Sb ppb		64	49	
Te ppb				
Cs ppm		<0.05	<0.06	
Ba		38	30	<81
La		4.95	4.53	5.3
Ce		14.2	15.2	15.6
Pr				

Nd	12.1	11.7	10.2
Sm	4.53	4.11	4.4
Eu	1.37	1.26	1.37
Gd	5.7	5.4	
Tb	1.05	0.99	1.1
Dy	7.1	6.9	7.5
Ho			1.63
Er			
Tm	0.73	0.67	
Yb	4.71	4.49	4.8
Lu	0.68	0.64	0.72
Hf	2.89	3.1	3.08
Ta	0.29	0.32	0.33
W ppb	120	90	
Re ppb			<0.06
Os ppb			<270
Ir ppb	<2	1.1	50
Pt ppb			
Au ppb	0.9	1.3	<50
Th ppm	0.69	0.67	0.75
U ppm	0.12	0.07	

technique (a) ICP-AES, (b) ICP-MS, (c) IDMS, (d) Ar, (e) EMPA, (f) RNAA, (g) INAA, (h) wet chemistry

Table 1b. Light and/or volatile elements for **Yamato 793169**

Li ppm		
Be		
C		
S		
F ppm		
Cl		
Br	0.14	0.18
I		
Pb ppm		
Hg ppb	<0.2	<0.1
Tl		
Bi		

1) Yanai and Kojima (1991); 2) Koeberl et al. (1993); 3) Warren and Kallemeyn (1993)

K. Righter, Lunar Meteorite Compendium, 2010